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Current Status and Future of Structural Panels in the Wood Products Industry

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Abstract

The technical, manufacturing, economic and policy considerations which are shaping innovation in structural wood panels will be briefly examined. A model of the substitution of newer panel forms for plywood, done in 1980 when market penetration was about 3 percent, will be presented. More recent data will be used to reexamine the model and validity of the Fisher-Pry technique in this instance.

INTRODUCTION

For decades, plywood has been the dominant structural panel in U.S. light frame construction markets. In recent years, however, its status has been threatened by new generations of replacement products.

This report analyzes the causes which have led to these new product introductions. Key variables affecting future success of the new panels and plywood's vulnerability are analyzed. The role of product performance in establishing markets via building code approvals is discussed and a summary of current code approvals in the industry is assembled. Potential new markets available to the replacement panel types are described.

On the basis of technological, economic, political, and market arguments, a forecast for the future of the U.S. structural panels business is presented as it was reported in 1981. More recent data are used to update and check the model.

One of the most highly fragmented and decentralized industries in the United States is that of building construction. This is particularly true for the construction technique which is most often applied to the activity of building residences - known as "light frame construction." The decentralization and fragmentation inherent to this branch of the construction industry historically has created roadblocks to innovation both in construction systems and in the materials and components which provide the ingredients to those systems. The problems of innovation are in large part problems associated with making more sophisticated an activity which by its very nature is required to take place a numerous decentralized sites.

Arthur D. Little [1] has viewed the fragmentation in the light-frame construction industry as occurring on two levels. First, the industry is made up of thousands of relatively small companies (although trends over the last decade have been toward some consolidation of construction contractors). Second, these

small firms represent many diverse segments of construction activity: architects, designers, structural engineers, and suppliers and manufacturers of components and construction materials. Because each of these participants carries out his activity in the context of his own concerns and standards and attempts to maximize his own personal individual profit, no one emerges with responsibility for the overall building task. For a newly initiated innovation to be diffused throughout this system, each participant must recognize and accept it. However, he is unlikely to do so unless it provides him with an incremental economic pay-off or, at most, does him no economic harm. All participants must, therefore, be sold on the merits of an innovation before it can be successfully implemented. Because the interests of these key actors are frequently incompatible, getting such a consensus is difficult.

The wood products industry is the primary construction materials supplier to the light frame construction industry. For decades it has supplied lumber and panel products to suppliers or directly to contractors for on-site assembly into single- or multi-family residences. These wood products are standardized commodities, manufactured and distributed in standard grades and sizes. Combined with the institutionalized conservatism within other sectors of the light frame construction industry, they have led to proliferation of house configurations and sizes chosen so as to make optimum economical use of the standard component sizes available.

Despite the anti-innovation climate in light frame construction, the wood products industry has been responsible for initiating significant changes in building practice. Especially notable were changes in the area of structural panels. After World War II, plywood, which had actually been introduced over forty years earlier, began to be utilized in light frame construction in ever-increasing volume. Because of the structural flexibility inherent to a panel, plywood gradually displaced lumber as the dominant sheathing material for floor, wall, and roof construction. Because its overall in-place costs were lower than those of boards, builders across the U.S. gradually shifted to the use of these structural panels and, in the process, willingly absorbed short-term discomfort and inconveniences within their operations.

Since the early 1950s, plywood has been the dominant structural panel in light frame construction. In recent years, however, for a variety of reasons, plywood as a product has been subjected to intense market pressure. New generations of replacements for plywood are being introduced by the wood products industry. A revolution is underway, the proportions of which are highly unusual for such a conservative and tradition-bound industry.

This paper focuses on new products that have been introduced as replacements for plywood in light frame construction applications, and in particular on the emergence of oriented strand board as a plywood substitute. The paper will describe some of the forces which have driven the development and acceptance of plywood replacements. A 1982 forecast of the rate of substitution of structural panel alternatives for plywood is presented. The forecast, based on the Fisher-Pry model, was thought to be too optimistic when first generated. Recent data are used to reexamine the forecast's value.

Plywood

As a product life cycle model, the curve generated by plotting historical sales of plywood (Figure 1) has several extremely interesting features. First, it has a classical S-shape, with a relatively flat (except for the years of World War II) introduction phase up to about 1948, followed by a rapid growth phase from 1948 through about the mid-1970s, followed by what appears to be a flattening, albeit erratic, mature phase since that time. Growth of plywood production through the 1950s and early 1960s was primarily due to west coast expansion, while growth through the late 1960s and early 1970s was due principally to increases in Southern pine plywood volumes.

The violent up-and-down swings in plywood production throughout the 1970s are due to the erratic nature of the overall wood products economy during that decade. The steep drop in production in the mid-1970s coincides with the nation's recession during that period, during which housing construction sank to very low levels. The steep decrease through which the industry is currently suffering is largely due to the ongoing severe slump in housing construction, perhaps the worst in magnitude since the Great Depression.

Current thinking within the industry is that, even if strong resurgences in housing construction occur, plywood's long-term outlook is one of no growth. End use markets have saturated as the process of plywood substituting for lumber has been completed. More significantly, plywood's long term outlook in its significantly large volume structural applications in construction is threatened by an emerging family of replacement products. The analysis of these new products forms the crux of this paper.

What factors have led to the development and market introduction of new panel products to substitute for plywood, which itself was a significant commercial innovation? An analysis of the technological, raw material, market and political influences driving this ongoing wood products revolution is the subject of the next section.

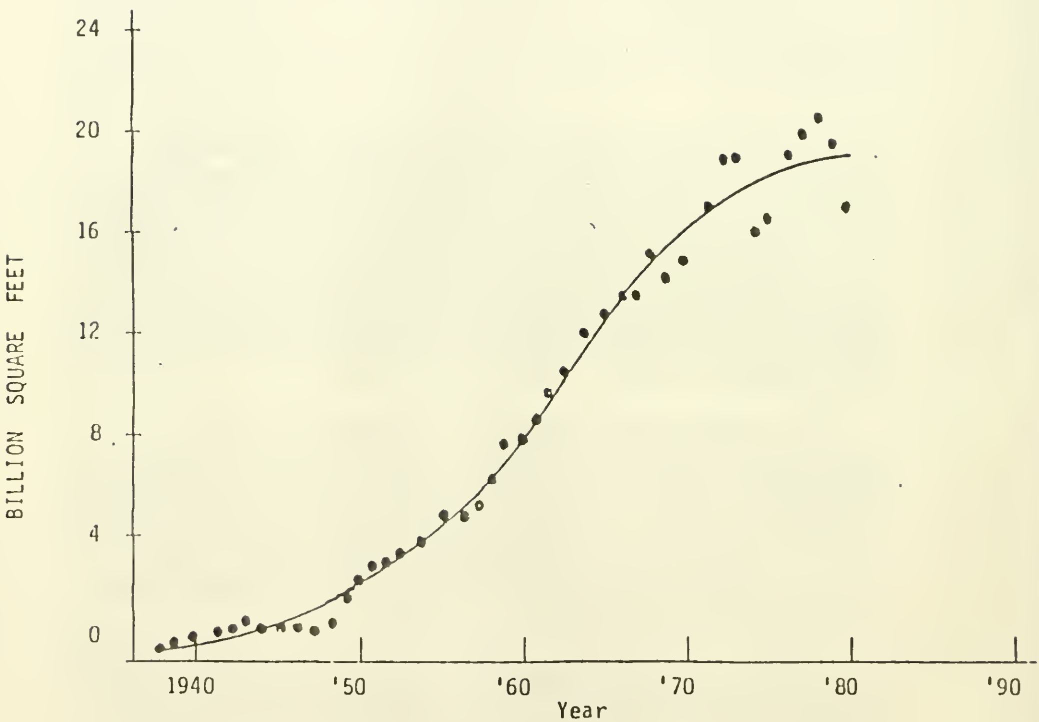


FIGURE 1

HISTORICAL PLYWOOD SALES

REASONS FOR DEVELOPMENT OF PLYWOOD REPLACEMENTS

There have been several recent developments in both the construction industry and in the wood products industry which have together provided the impetus for major producers to introduce panel products to replace plywood in the construction end use applications in which historically plywood has been dominant. These developments can be categorized an analyzed under four general headings:

(1) Technological;

(2) Raw Material;

(3) Market;

(4) Political.

Technology-Related Developments

It has been well-known for years among researchers and forest products technologists that it is possible to process particle-based panels in the laboratory so as to achieve panel physical and mechanical properties at a sufficiently high quality level to suggest the possibility of using in structural applications panels not made entirely of veneer. It is only fairly recently that production scale technologies have demonstrated the feasibility of duplicating these laboratory panels at an acceptable level of quality and in commercial quantities. Process development the last few years has been rapid as wood products manufacturers and processing equipment manufacturers have together sought out and developed alternative means of manufacturing varieties of flat structural panels. Resulting processes in use are similar in configuration and overall flow to those used in the industry for production of particleboard and fiberboard. Demonstration of the viability of these processes for producing truly structural panels has provided great impetus to the introduction by the industry of new panel types.

Raw Material Developments

During the last decade the most critical problems affecting the plywood industry have been timber supply and cost. Primarily as a consequence of withheld and withdrawn timber from public

TABLE 1

RECENT TRENDS IN WESTERN OREGON STUMPAGE PRICES

Year	Average Stumpage Price ($ Per 1000 Board Ft.)	Year-To-Year Change
1976	141.54	--
1977	181.51	+28%
1978	210.96	+16%
1979	332.09	+57%
1980	354.60	+ 7%

lands, the cost of timber throughout the 1970s and into the 1980s escalated far beyond inflation rates [2]. Extremely rapid increases in timber costs started in the mid-1970s as the timber management teams of public lands began to withhold timber that could conceivably have been offered for sale to producers under the U.S. Forest Service sustained yields allowable cut philosophy. During succeeding years, characterized by litigation, politics, and inadequate government funding for sale, the average timber stumpage prices for western Oregon logs escalated as shown in Table 1 [2]. (Note: The term "stumpage" refers to the value of timber "on the stump;" i.e., prior to harvesting and transport to a production facility). The rate of stumpage price increases has slowed noticeably in 1980 and 1981, due to the ongoing housing and plywood industry recession. The American Plywood Association (APA) points out [2] that, even though the rate of increase has slowed, it is nevertheless still increasing which is counter to experience in past recessions during which stumpage prices decreased. Complicating this severe raw material problem have been inexorably increasing labor, energy, and adhesive costs, with the end result being immense cost pressures on the plywood industry.

Rates of raw material price increases in the southern and inland region, while not as steep as in the west, have nevertheless exceeded inflation rates.

Concurrent to these plywood raw material cost pressures has been the wood products industry's recognition of the attractiveness of vast pockets of a hitherto ignored species - aspen - in Canada and the upper midwestern U.S. This species has characteristics making it essentially ideal for production of particle-based structural panel types. The industry has also recognized the equally attractive spruce and mixed soft hardwood stands in the northeastern U.S. and the slightly less attractive mixed hardwood stands in the south as candidates for raw material sources. In contrast to the escalated prices thrust upon plywood producers for their raw material, these emerging raw material sources for new panel production have had little or no historical demand. Hence, they have affixed to them negligible or very low stumpage prices.

Thus, from the perspectives of both plywood processing technology and emerging panel processing technology, raw material issues have provided significant impetus to the development of new panel types.

Market Developments

In addition to - and perhaps contributing to - the rapid price increases for plywood raw material has been the gradual

disappearance of the types of round, straight, large diameter, old-growth logs historically ideal for plywood production. As these have gradually been used up, in their place have appeared lower grade old-growth logs, and second-growth logs emerging as a result of government and private firm forest regeneration practices. Neither of these two categories represent raw material quality on a par with that historically preferred by plywood manufacturers. As a result of having to accommodate lower quality raw material, plywood producers have over the last decade been producing a product having gradually diminishing quality. While it is difficult to find in the literature a succinct appraisal of the decline in plywood's quality, there is throughout the wood products industry and among the construction and retail sales sectors a prevailing feeling that "plywood is going downhill." Even western plywood, which because of Douglas fir's quality advantage over Southern pine has had a performance and acceptability edge over southern plywood, has exhibited steadily declining quality during the last several years.

This inexorable decline in product characteristics has not been lost upon the market. It has been assimilated and reacted to to such a degree that even such a conservative industry as light frame construction has expressed receptivity to alternate types of structural panels. the prevailing feeling in the construction market has been: "If a panel will do plywood's job and does not require me to significantly change my on-site practices, and if I can get it at a lower cost than plywood, I'll try it."

Political Developments

A major incentive for current and future planned expansions in structural panels has been the emergence in the last two years of an alternative approach for the qualification and certification of sheathing products. Historically, the plywood industry, as well as the particleboard and fiberboard industries, have manufactured products against and according to the provisions in industry product standards. The APA and the National Particleboard Association (NPA) have been the primary industry bodies representing their respective generic product types. Recognized by the building code regulatory agencies, these product standards - PS1-74 [3] for plywood and ANSI A08.1 [4] for other panel products - have been the vehicles by which the industry has qualified products. Furthermore, they have provided criteria against which production panels can be tested to certify their quality.

Since 1976, the APA has worked on revolutionary new procedures for accomplishing these qualification and certification objectives. This work has culminated in

publication and acceptance of new standards based on the concept of product performance. The main feature of these new standards is a new performance-based approach versus the prescription approach embodied in the historical product standards. The emergence of these standards provides an obvious philosophical incentive for introduction of a sheathing panel differing in characteristics from plywood assembled according to an existing prescription standard.

Having laid sufficient plywood historical background to put the current sheathing market in context, and having analyzed the incentives and issues which have set the stage for development of new sheathing panel types, it is timely to present a discussion of the innovative new product types which have been introduced by the industry.

THE NEW PANELS

The new structural panel products recently introduced fall into three basic types. The first, referred to under the generic heading of waferboard, had its commercial introduction in 1966 in Canada, and has recently been experiencing considerable growth in production volume both in Canada and the U.S. The second type, known generically as COM-PLY, has been commercially available since 1976. The third type, usually discussed under the general label of oriented strand board (OSB), has only recently been introduced to the sheathing market, having been first commercially produced in 1981. Each of these three product types possesses characteristics making it unique from the other two. These differing characteristics range from appearance to physical and mechanical properties.

All of these three plywood substitutes are marketed as structural sheathing commodities, although their characteristics, appearance, and performance differ to a considerable degree. In spite of significant differences, each of these three product types has emerged as a viable substitute for plywood in structural use.

Waferboard

Waferboard is an unveneered, structural use panel. First produced in Canada in 1966, it has since spread to several Canadian and U.S. manufacturing locations.

Though it is manufactured under various tradenames, waferboard is essentially a generic product type with only minor differences from one manufacturer to the next. It is generally manufactured from low density hardwoods (most predominantly aspen), although at least one manufacturer accomplishes production using spruce.

COM-PLY

The term COM-PLY was coined by the APA to describe a class of hybrid panels composed of a combination of wood flakes or particles and resin, sandwiched between two sheets of veneer which make up the face and back of the resulting panel. On the surface, COM-PLY looks much like plywood because the veneer used for the face and back is identical to that used for the same purposes in softwood plywood production. While plywood utilizes

veneer in its interior laminations - usually laid up with wood grain orientation alternating at right angles from layer to layer - COM-PLY utilizes wood particulate material formed in a number of ways as a single inner core "ply" between two sheets of veneer.

OSB

One drawback to waferboard has been its inherently low structural stiffness and strength characteristics relative to plywood. For example, a typical waferboard panel has approximately one-third of the modulus of elasticity in flexure of west coast Douglas fir plywood. A perceived need for panel stiffness and strength greater than that provided by waferboard has spurred the evolution of technology - both product and process development - which has led to the introduction of OSB.

OSB is composed of three layers of aligned strands which are similar to wafers but possess length much greater than width. In essence, strands are wafers which have been split across the wood grain so that they are much longer in the wood natural grain direction than across the grain. Strands in the panel top and bottom surface layers of OSB are aligned parallel to the panel direction, while strands in the core layer are aligned parallel to the cross-panel direction. In essence, the OSB panel configuration is a mimic of plywood's construction. Strand alignment in the surface layer imparts panel stiffness and strength, analogous to the role of plywood face and back veneers. Cross alignment of strands in the core elevate cross-panel dimensional stability, as do core veneers in plywood.

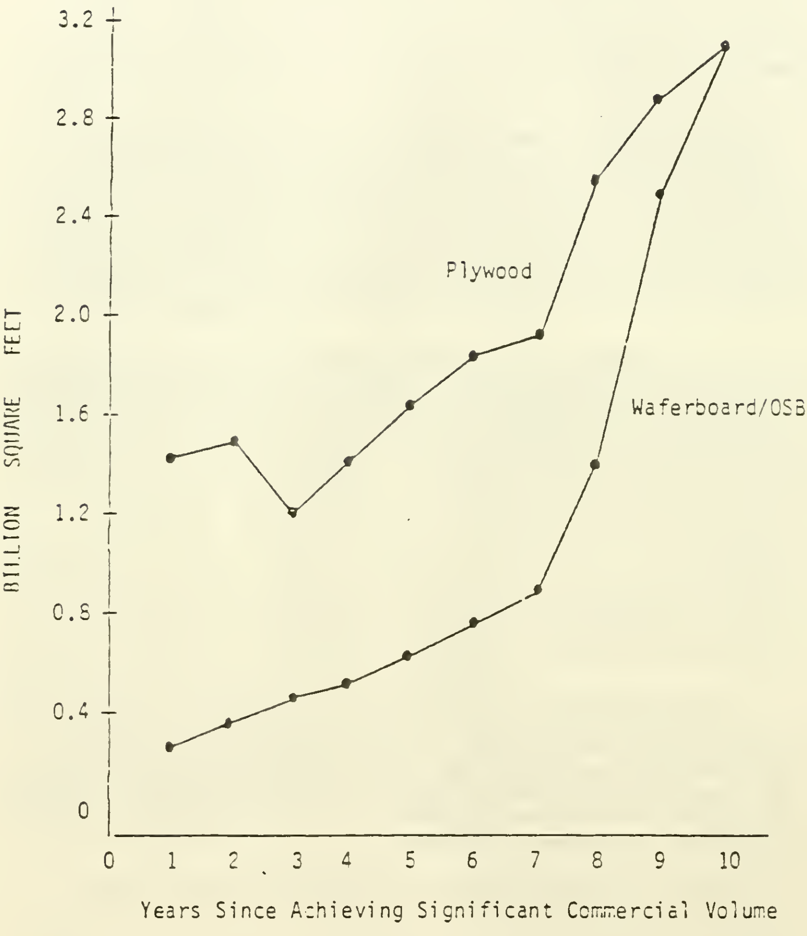
Another significant difference exists between waferboard and OSB. Whereas powdered phenolic resin is used as the adhesive in waferboard manufacture, OSB is currently bonded with phenolic resin which is applied in the liquid state during manufacture. The liquid type of adhesive application technology has advantages over powdered resin technology in the areas of product performance and process economics.

OSB has been demonstrated to be a product whose panel properties are very nearly equivalent to those of plywood.

As is clear from Figure 2, waferboards' initial introduction rate was considerably slower than that of plywood. However, as the rapid expansion of the last few years has unfolded and as waferboard is joined on the market by OSB - a product with which is shares many similarities - the rate of growth of the combined pair has far exceeded that which was exhibited by plywood. Furthermore, these high growth rates of the waferboard/OSB product family occurred during a deep

FIGURE 2

COMPARISON OF PLYWOOD AND WAFERBOARD/OSB GROWTH RATES



recession period in the U.S. and Canadian economies. While it is difficult to forecast with a high degree of accuracy future growth rates for new products, the rapid penetration of the new panels compared to plywood and the similarities between the markets of these panels with those of plywood suggest that the future for the waferboard/OSB product family is quite bright.

At this point it seems clear that plywood is a product on the defensive. New panels are being introduced - and accepted - at a rate which outstrips plywood's own historical experiences. Further, among the three product types, the one least likely, for economic reasons - and, ironically, the one most similar in characteristics to plywood - to have a large market impact is COM-PLY. A competition for dominance among the substitutes, then, appears to be unfolding between waferboard and OSB. Clearly, waferboard is the early leader in the race for dominant market share among the plywood substitutes. Its U.S. production capacity through 1983 was projected to exceed 1.1 billion square feet, while announced OSB capacity totaled 680 million square feet. When the U.S. waferboard production capacities are combined with a portion of Canadian waferboard production (which was projected to exceed 1.1 billion square feet in total), there will be potential for considerably more waferboard than OSB to appear in U.S. light frame construction.

However, OSB is a very recent market entrant which has been developed to provide a product with properties closer to those of plywood than are waferboard's. It is fair to assume that the relative success of each of these two products should depend on their respective product characteristics. How they compete should also depend on their delivered prices and the returns on investment these delivered prices yield to manufacturers. These returns depend in turn on manufacturing costs the magnitude of which hinge on process configuration and economics. Hence, even though waferboard is the clear early leader in competition with newly introduced OSB, it should not a priori be conceded a long term advantage. It is first necessary to analyze in detail the product performance, process, and manufacturing/market economics issues existing between the two product types.

Waferboard is composed of large, square flake particles, while OSB is made of long, narrow, strand-like flake particles. Although significantly different in appearance, these two products are produced in manufacturing processes which share numerous common features. A block diagram of a typical waferboard manufacturing process is shown in Figure 3.

In this typical waferboard process, de-barked log segments are fed to flaking machines which generate the chiplike wafers required in the product. These wafers are in turn dried in large drum dryers to approximately 2 to 5% moisture content (based on dry wood weight). Dry material then flows over gyratory screens

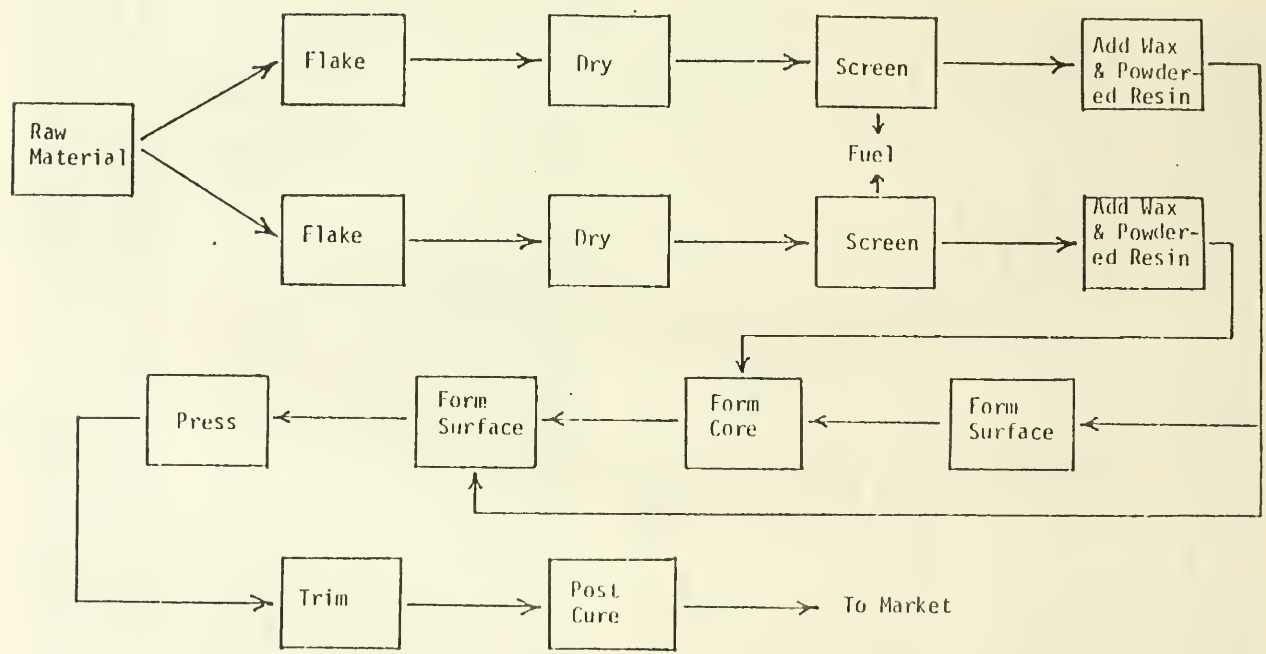


Figure 3

Idealized Typical Waferboard Process

which remove extremely small, undesirable particles (called "fines"). These fines are then used as dry fuel, typically in suspension burners to generate thermal energy for the dryers. Wax (for liquid water resistance in the final product) and powdered resins are added to the dried and screened material in tumble drum blenders. All these processing steps take place in two separate parallel lines, one generating material for the panel surface layers and one generating material for the panel core layer. Core layer material is normally smaller in size than surface layer material for reasons of product performance, leading to the requirement for separate parallel lines. From the blenders material is transported to surface or core forming machines. These pieces of equipment lay down a mat of wafers in three sequential layers - bottom surface, followed by core, followed by top surface - which, upon completion of forming, is fed into a hydraulic hot press for consolidation and adhesive curing. Pressed panels are removed from the press, trimmed to size (typically 4 feet by 8 feet for construction sheathing panels), and placed in "hot stacks" for further curing of adhesives, taking advantage of latent out-of-press heat remaining in the panels.

While simple conceptually, a waferboard process is highly capital intensive embodied in expensive equipment which is kept running within a plant around the clock. The process is continuous, with the particle stream flowing somewhat similarly to the motion of a fluid through the unit operations from flake to final panel.

Figure 4 depicts a block diagram of an OSB manufacturing process.

Only a quick glance at Figure 4 is required to reveal the interesting fact that there are only a small number of seemingly minor differences between this process and the waferboard process of Figure 3. These differences are essentially three in number:

(1) In OSB manufacture, flaked material is split across the wood grain to convert wafers into strands which can be aligned in the forming unit operation;

(2) Flaked and dried material is blended with liquid resin; application of liquid resin to wafers has been a long-standing goal of waferboard producers [5]; for technical reasons this has never been achieved with wafers, but has been accomplished with strands; use of liquid resin is desirable because of liquid's higher efficiency which will be seen in comparisons of product properties;

(3) Parallel alignment of the strands in OSB manufacture

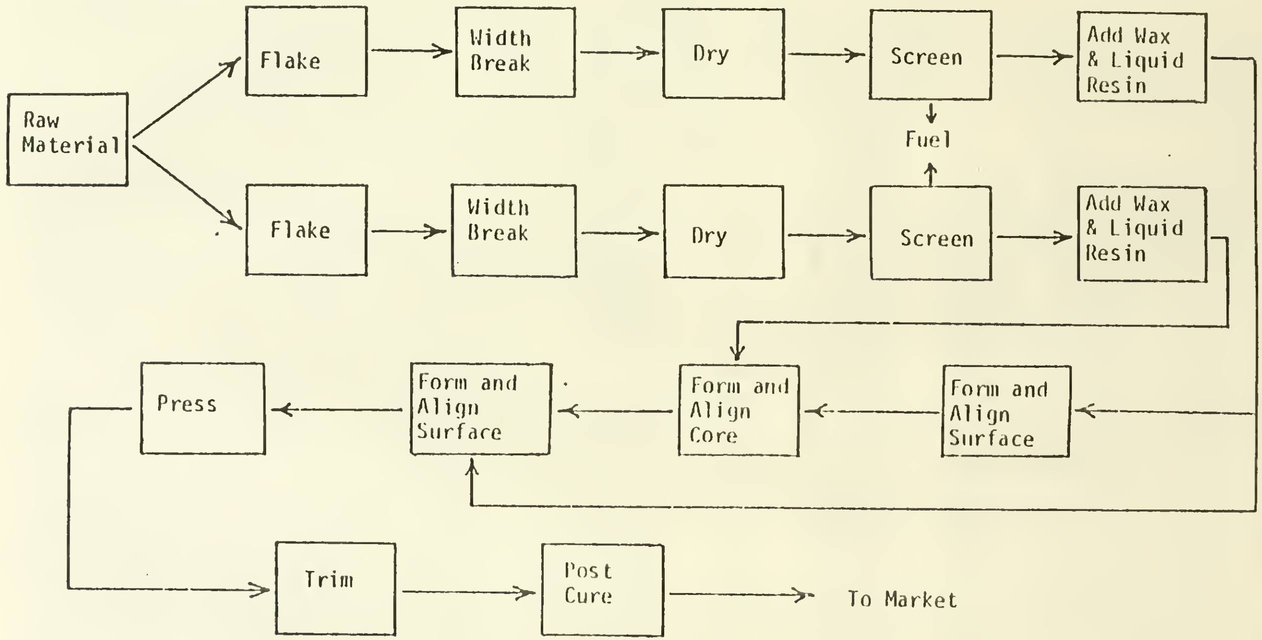


Figure 4

Idealized Typical OSB Process

is accomplished during the forming operation, leading to the three-layered configuration will aligned surface layers and cross-aligned core.

Capital estimate studies done at Weyerhauser [6] have indicated that incremental capital required for retrofitting an existing waferboard process to OSB capability is less than 10% of the capital required to build the initial waferboard process.

One area of incremental benefit lies in the relative receptivity of the two processes to lower grade raw materials. One of plywood's most serious shortcomings has been its inability to accommodate lower grades of raw material in its process and still produce an acceptable panel. The reconstitution inherent to waferboard's and OSB's processes is much more robust in being able to utilize less desirable raw material and still make a panel which has adequate properties. OSB has a slight advantage over waferboard because of the higher general overall bonding efficiency of the liquid resin it employs.

This flexibility alone, however, would not seem to justify the rush to OSB. Other, more sizable benefits must be accruable to OSB. Such benefits can be demonstrated, due directly to the improved product performance characteristics of OSB.

Because sheathing-type applications in light frame construction represent the primary end use market outlets for these panels, the product characteristics critical to performance as sheathing are of primary interest. These important product characteristics include weight, stiffness and strength (particularly in flexure), dimensional stability, and durability. A discussion of the role each of these characteristics plays in the overall acceptability of a structural panel, as well as comparisons involving the new panels and plywood, follow.

Weight

In terms of weight per unit volume, west coast plywood is clearly the lightest structural panel produced by the industry. Next lightest is southern plywood, followed by COM-PLY, whose weight exceeds that of plywood because of its higher density, particle-based core. Slightly heavier is OSB, and finally waferboard. OSB is a little lighter than waferboard because the strand alignment slightly reduces wood and resin requirements.

While weight has little direct influence on panel performance in service (i.e., on a roof, floor, or wall), it is nevertheless important for two reasons: first, heavier weight dictates increased transportation costs; and second, heavier weight has some effect on user - particularly contractor - preferences.

Stiffness and Strength

By far the most important properties for structural panels are stiffness and strength. Because these panels are required in end use to be load-bearing members, and because the applied loads are panel-type loads, flexural stiffness and strength are of paramount importance. Of almost equal importance are panel resistance to racking and impact loads, and panel properties in tension, compression, and shear. In order to perform acceptably, panels must meet minimum standards in each of these property categories.

Bending stiffness is measured by modules of elasticity (MOE), and bending strength is measured by modulus of rupture (MOR). Through-the-thickness panel tensile strength is measured by internal bond strength (IB).

Comparisons reveal that OSB properties are essentially on a par with those of plywood, while those of waferboard are somewhat lower. It is the aligned strand configuration of OSB which enables it to deliver properties similar to plywood's, as is expected due to the conceptual similarity of their respective constructions. Waferboard, on the other hand, being assembled into a less sophisticated configuration, possesses inferior properties.

Dimensional Stability

Dimensional stability was earlier defined as resistance to expansion and contraction due to changes in moisture content brought on by environmental conditions. The dimensional stability of panels is typically assessed by measuring two parameters: the in-plane expansion of a panel resulting from a large change in atmospheric relative humidity measured between two standard conditions, and the swelling of the panel through-the-thickness brought on by the same changes in condition.

Dimensional stability is an important indicator of panel performance because of the fact that panels used in construction often get wet on the job site (due to rain or humidity) and consequently, do expand. While not all panels necessarily are wetted, many do get saturated during the construction process. This is particularly true for floor panels. As a result of this expansion, panels butting against one another have the potential effect of buckling between framing members or even moving out

walls or partitions in the structure. Thickness swell has cosmetic importance, due to the undesirability of having differential expansion of adjacent panels which can cause finish flooring materials (tile and carpeting) to buckle unattractively.

There are small but not significant differences in linear expansion values among panel types. COM-PLY is slightly more prone to thickness swell than plywood, with OSB somewhat worse than COM-PLY, and waferboard the worst of all.

Durability

A final panel performance characteristic of critical importance to sheathing applications is durability, which can be defined as long-term retention of properties. Traditionally, the durability of panel products has been assessed using various accelerated aging tests. These measure the strength of test specimens, then measure the strength of similar samples after they have been subjected to several heat, moisture, cold, and dry cycles meant to simulate the effects of many years of service. Durability is indicated by the ratio of strength after accelerated aging to initial strength, sometimes referred to as "strength retention." OSB performance is essentially on a par with plywood and COM-PLY performance, and waferboard's performance is considerably lower. Technically, waferboard's inability to match OSB's strength retention is due to the powdered resin system it utilizes, as opposed to OSB's more efficient liquid resin system.

Summary

While these comparisons of structural and engineering characteristics of wood-based structural panels have been brief, two significant conclusions appear to be inescapable:

(1) COM-PLY and OSB are about comparable to plywood on all important bases except weight (i.e., density);

(2) Waferboard is inferior to the others in nearly all product characteristics, with lower stiffness, strength, and durability and greater weight.

At this point there seems to be a dilemma for the industry. Waferboard has been a commercially successful product since its initial introduction, yet all the data presented indicate that

it is a markedly inferior product. To date its competition as a substitute for plywood has been with COM-PLY, the latter of which likely will not be a major market force for reasons of economics. Has waferboard succeeded because plywood has been historically an "over-built" product for its markets or has waferboard succeeded solely for reasons of costs and price discounts? Will waferboard continue to succeed? Will the introduction of OSB, with its superior characteristics, complicate waferboard's market picture? Is there some economic justification for additional producers to opt for OSB or for waferboard manufacturers to convert their processes to OSB capability?

A key to the success of the new panels will depend on their market acceptance. This market acceptance depends, in turn, on building code approvals, panel performance, consumer preference, relative price, and overall demand for structural panels. The most obvious areas of these five categories where product properties can be expected to exert an influence on acceptance are the first two: building code approvals and panel performance. The latter of these two categories, at least as far as structural performance (life safety) is concerned, influences the former.

The properties and characteristics of the new structure panel products have been compared both with each other and with plywood, the product for which they are marketed as substitutes. From the standpoint of product properties, COM-PLY and OSB are very nearly equivalent to plywood. Waferboard, on the other hand, is markedly inferior in characteristics. A comparison of the status of building code approvals shows that superior product characteristics have been recognized by regulatory groups in the form of panel thickness advantages which can be translated directly into market advantages.

For example, waferboard, because of its inferior properties, is usually required to be thicker than plywood when used as floor sheathing. OSB, on the other hand, can be significantly thinner than waferboard and even thinner than plywood in this end-use application.

The study of these data suggests that the substitute panel type holding the most advantageous position, independent of any production cost considerations, is OSB. In fact, OSB's relative code approval position at this point is even better than plywood's in two applications, roof sheathing and floor sheathing, which together have comprised a large historical plywood volume outlet.

Having firmly established OSB as a superior product from a performance standpoint, it is next necessary to consider the competing substitute panel types from the standpoint of manufacturing costs.

MANUFACTURING ECONOMIES

A panel end use thickness advantage is directly translatable into additional monetary return only if not canceled out by any commensurate increased costs. How do the manufacturing costs of the various panel products compare?

Figure 5 graphically compares typical variable manufacturing costs for western and southern plywood, southern COM-PLY, and upper midwest waferboard and OSB. The costs displayed are in dollars per thousand square feet of 1/2-inch thickness. Variable cost line items are wood, adhesive, labor, energy (thermal and electrical), and other.

Several points of interest emerge from inspection of Figure 5. First, western plywood is the most expensive structural panel to produce, primarily because of its high wood costs relative to the other panels. Somewhat lower in cost is southern plywood. Slightly lower in cost than southern plywood is COM-PLY.

However, manufacture of COM-PLY requires two separate capital-intensive processes, each of which adds significant fixed cost components. When fixed costs are added to variable costs (in which southern plywood and southern COM-PLY differ only slightly), the higher COM-PLY fixed costs will result in that product's having little if any overall cost advantage relative to plywood.

Waferboard and OSB, on the other hand, have tremendous manufacturing cost advantages over the veneered products. A large part of this advantage is due to drastically lower wood costs, arising from the large difference in stumpage values between midwest aspen and western Douglas fir and Southern pine. Almost equally influential is the difference between labor costs. Plywood processes, by their nature, require much more labor than do waferboard and OSB processes, which are conceptually similar to capital-intensive particleboard processes. The only area where plywood has an advantage in cost is in adhesives where its costs are markedly lower than for COM-PLY, waferboard, and OSB. This can be considered to be a two-edged sword for the new composite panels. At the current stage of technology, adhesives used are phenolics which are derivatives of petrochemicals. Having a large portion of a product's manufacturing costs tied up in such additives can make that product extremely vulnerable to any future increases in the price of oil. On the other hand, adhesive technology development is in a neophyte stage for these products, and the high current adhesive costs can be looked upon as an opportunity for new technology to lead to future

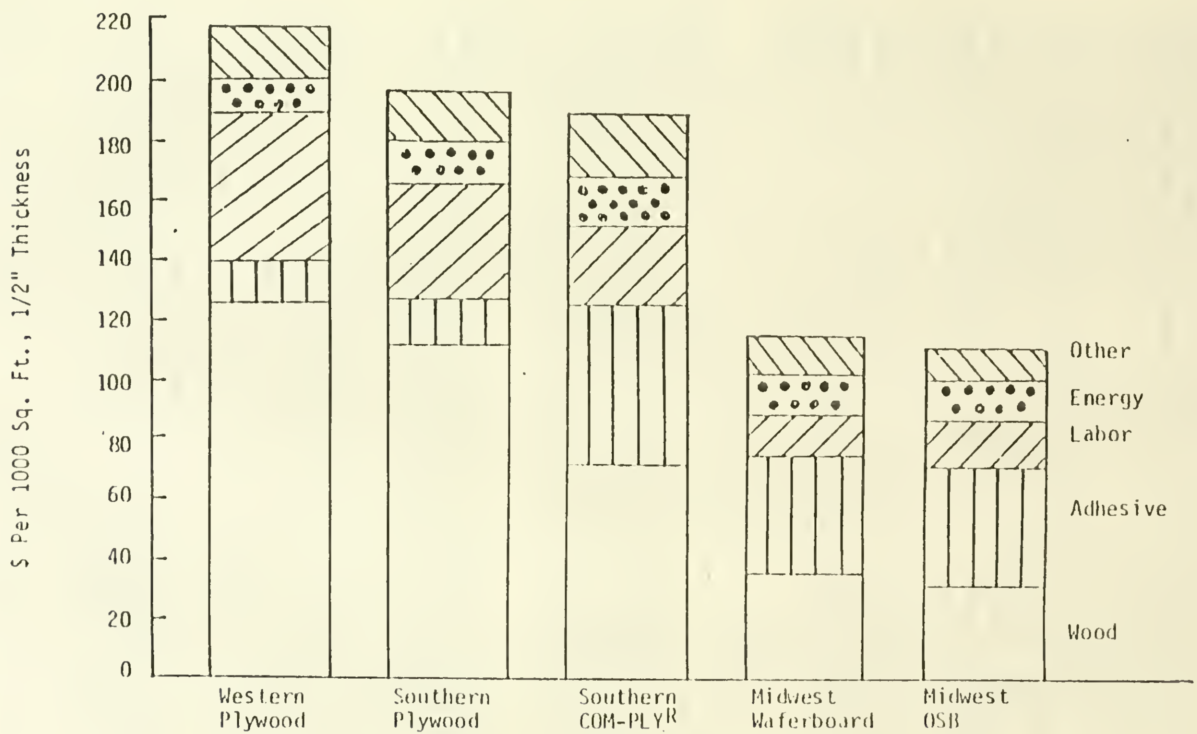


Figure 5

Comparison of Panel Variable Manufacturing Costs

significant cost reductions.

The traditional panel - plywood - is under severe cost competition from new panel types. One panel type - COM-PLY - has only a slight cost advantage over plywood. Waferboard and OSB, however, own significantly better cost pictures. OSB seems to have a very slight cost advantage relative to waferboard. The comparisons are not yet complete, however. Up to this point the products compared were all of the same thickness. Considering code approvals and likely end use market break-downs, this is not a comparison which accurately and fairly takes into account the relative performance characteristics of the different panel types.

Recall that, in some end uses, the inferior properties of waferboard have resulted in its being marketable only at thicknesses which exceed those of plywood and OSB. In addition, recall that OSB possesses a thickness advantage in some end uses not only over waferboard, but over plywood as well. In order to compare the implications of these end use issues on producers and manufacturing costs, the data of Figure 5 have been re-assembled into the format of Figure 6. This chart compares variable manufacturing costs for each product for a particular end use category - floor sheathing - in terms of dollars per thousand square feet of marketable panel.

Figure 6 gives a truer comparison of the relative cost advantages of the four panel types in this end use as seen by the producer. Quite clearly, what emerges from this comparison is a picture of OSB as a product with not only performance advantages over waferboard, but also significant cost advantages which are directly traceable to its improved performance characteristics.

In conclusion, a number of points can be summarized:

- Plywood is, and will continue to be, at a severe cost disadvantage relative to the new panels;

- COM-PLY possesses at most only a slight cost advantage over plywood;

- Waferboard and OSB, primarily due to lower wood and labor costs, have a much better current and projected cost picture than either plywood or COM-PLY.

- In the largest volume end uses - roof and floor sheathing and single floor systems - OSB has a significantly cost posture than does waferboard and, of course, a tremendously better cost posture than does plywood.

The focus of the discussion so far has been on light frame

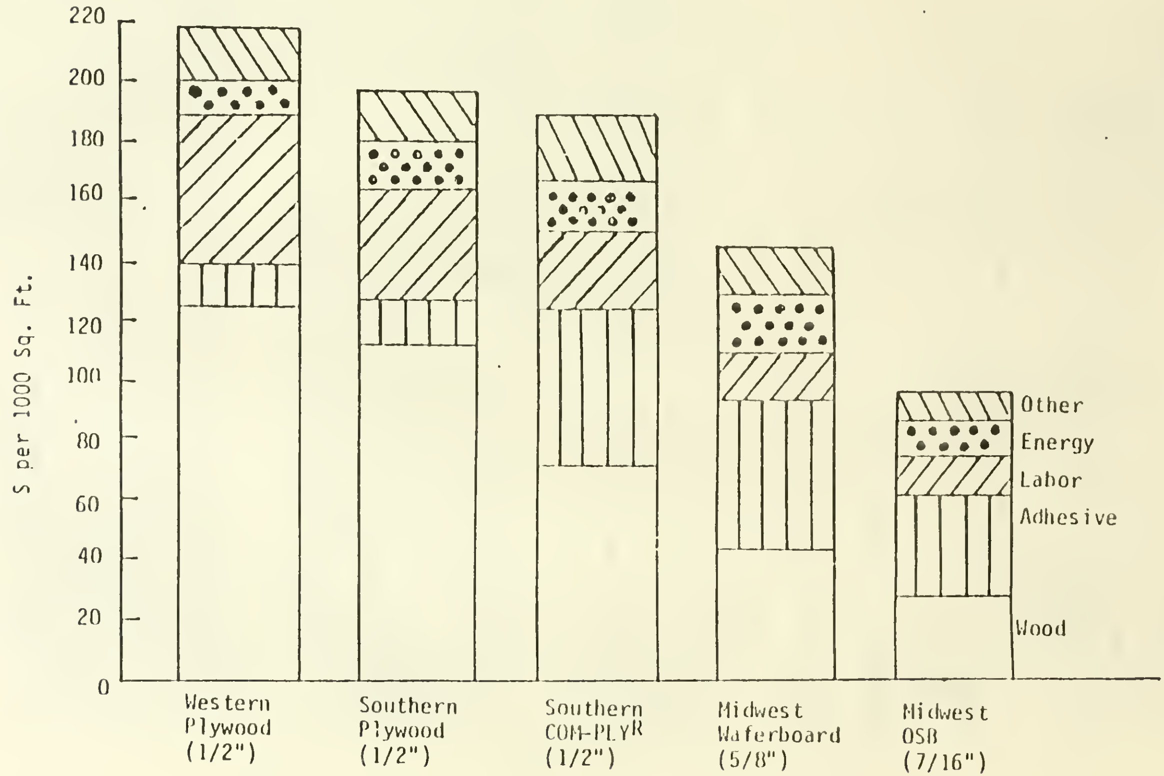


Figure 6

Comparison of Variables Manufacturing Costs for Floor Sheathing

construction applications of structural panels which have collectively accounted for a large proportion of plywood's historical production. It is useful at this point to systematically look at plywood's potential vulnerability to invasions of all of its traditional markets. This will help to arrive at an accurate overall picture of the likely progression of this ongoing substitution movement.

According to a Kidder-Peabody assessment, nearly half (48.2%) of plywood's 1976 sales categories are highly susceptible to the new panel invasions, and less than one-tenth (7.1%) have low susceptibility. The remainder are in the medium category.

A few of Kidder-Peabody's assessments are arguable. Wall sheathing is certainly a highly susceptible end use, as are concrete forming applications, yet both categories were related as medium by Kidder-Peabody. If these adjustments are made to the Kidder-Peabody summary, 55.3% of plywood's end use markets can be subjectively rated as highly susceptible to new panel penetration. Among these categories are all structural applications in light frame construction and nonresidential and farm building, as well as a variety of other end uses for which the "appearance" of plywood does not play a critical part. Together these categories constitute a significant portions (a majority!) of plywood's end use markets.

On the basis of these subjective ratings, it is fair to hypothesize that, at least theoretically, the new structural panels have the potential to penetrate into most plywood end markets. Much of the penetration is already vigorously underway, in the form of penetration of waferboard and COM-PLY into new residential construction.

Having the "potential" to make large scale penetration does not alone guarantee success for the new panels. It has been shown that these panels have achieved regulatory acceptance, have significant cost advantages, and can be expected to perform in service in at least an acceptable manner. The likelihood of success for these panels, however, rests not on these factors but also on other economic factors as well, such as overall demand, delivered costs, and marketplace acceptance.

In summary, plywood markets are extremely vulnerable to incursion by the new panel types. There are several key factors influencing the success - current and future - of these new panels, foremost among them being overall demand for structural panels and price. Whether overall demand for structural panels is high or low, the new panels have advantages in cost and/or performance which give them sufficient price flexibility that they should significantly penetrate plywood markets. High demand will lead to fast penetration, low demand to slower penetration (in volume, but likely not in rate). Among the new panel types, OSB possess the most advantageous combination of cost and performance.

FORECAST

Having presented a discussion of incentives which have arisen to provide motivation for development of substitutes for plywood and descriptions of the members of the new generation of panels, and having presented a sufficient analysis of important technological issues to enable summarizing of plywood's vulnerability to attack, it is useful at this juncture to attempt to summarize the overall status of the structural panel industry.

First, by 1982, the western plywood industry was undergoing considerable consolidation. Although a number of mill closures in the west were directly motivated by a severe slump in housing construction, much overall western plywood market share had been gradually lost, first to southern plywood and then to both southern plywood and the new panels. Inland plywood production continued to dominate its geographical area but was losing competitiveness in the midwest. Western plywood product mixes were moving increasingly away from structural grades and into specialty and sanded products.

Southern plywood, after its heyday of expansion in the late 1960s and early 1970s, seemed to have plateaued in growth. Because of its lower manufacturing costs and logistics advantages in many major markets [7, 8] relative to western plywood, it weathered the onslaught of recession and the invasion of the new panels more successfully than its western counterpart.

While western plywood was declining and southern plywood plateauing, both panel types faced increasing competition from the new panels. These panels are extremely cost (and price) competitive. COM-PLY had good market acceptance. Waferboard had good market acceptance in the end uses where it had been marketed. Building code approvals for these products provided a major impetus to their acceptance. OSB, which can be thought of as essentially an improved version of waferboard was just coming on stream. It has improved performance characteristics and achieved code approvals which would seem to give it significant advantages over waferboard. It also has a large cost advantage over plywood and COM-PLY. A tremendous expansion in capacity in waferboard and OSB had been added in the industry.

In 1979, total U.S. plywood production (including COM-PLY) was 23.1 billion square feet, while waferboard capacity in Canada and the U.S. together totalled 844 million square feet [8]. It was thought, in 1982, that by 1984, the total North American capacity in waferboard and OSB would exceed 3 billion square feet.

In summary, the following predictions were made in 1982: Waferboard, a low cost substitute for plywood sheathing, is inferior in performance to plywood but sufficiently cost competitive to have allowed it to make significant market in-roads in construction applications. Its favorable price relative to plywood has allowed it to fare relatively well throughout the construction market. It will not enjoy wholesale acceptance because of its performance shortcomings which require in some end uses thicker and, therefore, markedly heavier panels. Because of its large volume it could establish pricing discount range relative to southern plywood.

OSB is an improved version of waferboard at slightly lower overall manufacturing costs. It is equal to or better than southern plywood in performance. Because of its improved properties, it possesses plywood's versatility (e.g., can be used with confidence in single floor systems). It has the potential for wholesale acceptance.

In the competition between waferboard and OSB, the issue of price will be critical. The entry of waferboard was facilitated by the price discounts it offered relative to plywood. As more waferboard volume comes on stream and as OSB becomes available in larger volume, pricing competition will intensify. Plywood will continue to lose market share. Once available plywood markets are fully penetrated, competition between waferboard and OSB will intensify. The profitability of the new waferboard and OSB manufacturing facilities will depend greatly on the prices they are able to command for their respective products. In the absence of a huge surge in overall demand for structural panels, competition between waferboard and OSB will tend to hold these prices down.

Because of OSB's slightly lower overall manufacturing costs and possible premium in price, and because the difficulty of converting an existing waferboard facility to OSB capability is relatively minor, there will be a movement among waferboard producers to change to OSB. Being a superior product with cost advantages (and possibly price advantages), OSB will be recognized by alert waferboard producers as the product they should turn to. It is not likely that all waferboard producers will make the transition immediately, but over time OSB has the potential to become the dominant plywood substitute.

Waferboard and OSB will expand and begin to grab increasing market shares in the midwest and northeast. Manufacturers will begin to respond to the seasonality of demand in these regions by penetrating into the south. Eventually, production capacity will be introduced in the south - the APA reports [7] that several firms are looking there - as process technology enables the production of waferboard/OSB from low grade mixed southern hardwoods.

The process features (particularly large panel capability) inherent in waferboard and OSB will enable these products to move into new market areas as yet only slightly populated by plywood. At this point, the rate at which substitution of unveneered panels for plywood would continue was forecast using the Fisher-Pry method. [9] In their classical substitution model, these authors postulated that a technology which begins to replace an existing technology without a major change in function will tend to go to completion. Furthermore, they contended that the time and amount of substitution can be predicted according to a hyperbolic tangent function based on the average annual rate of replacement. In equation form:

$$f = 1/2\ [1 + \tanh a(t - t_{c})]$$

where,

f = fraction of takeover by the new technology in year t;
a = half the initial annual exponential takeover rate;
t_{c} = year in which $f = 1/2$

Treating waferboard and OSB as one product category (unveneered panels) and using plywood and waferboard production volumes from 1974 through 1979, and following the Fisher-Pry procedure, yields

$$a = 0.0711$$

For 1979, the waferboard per cent takeover rate was 3.60%. From the governing equation,

$$0.036 = 0.5[1 + \tanh 0.0711(1979 - t_{c})]$$

Solving yields

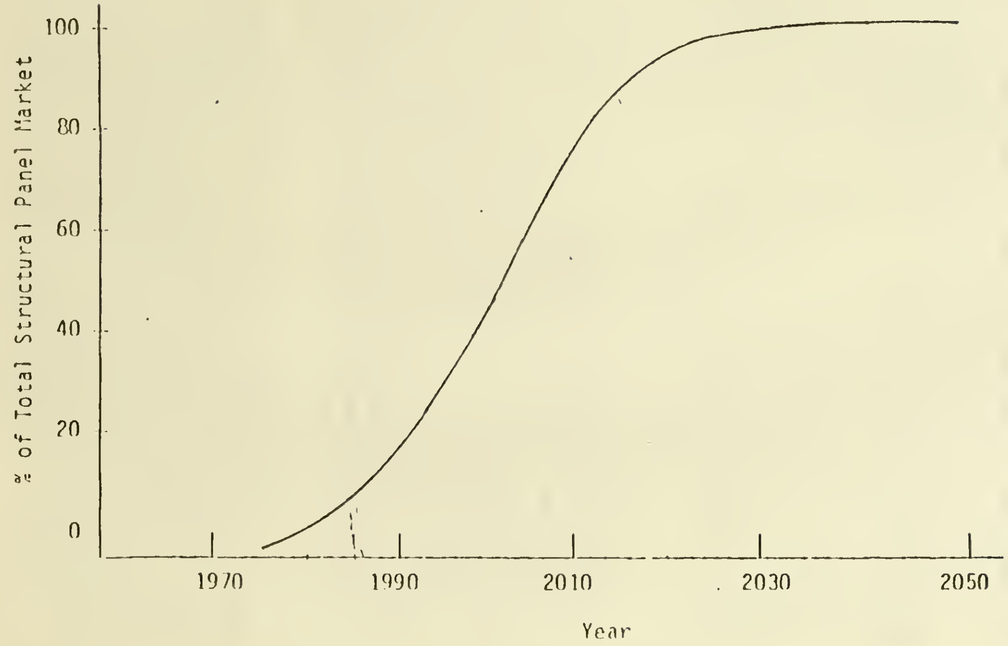
$$t_{c} = 2002$$

Thus, according to the Fisher-Pry model and the evidence available in 1979, it was forecast that half the U.S. structural panel market would be made up of unveneered panels by the year 2002.

The entire forecasted waferboard/OSB substitution curve, as calculated using this model, is depicted in Figure 7 which predicts that substitution for plywood will be essentially complete by 2030.

FIGURE 7

SUBSTITUTION OF UNVENEERED STRUCTURAL PANELS FOR PLYWOOD, AS PER FISHER-PRY MODEL



While the predictions of the Fisher-Pry model need not be taken literally, it was nonetheless clear that the waferboard/OSB product category possesses many advantages which will lead to eventual total substitution of plywood in sheathing markets. However, because of the importance of shipping and transportation costs in the highly regionalized U.S. wood products industry, achievement of this total substitution must await massive installation of production capacity in the west and the south to supplement what is already in place in the midwest and northeast.

This forecast was believed by many at the time to overstate the potential of OSB/waferboard for substitution for plywood. The forecast will now be reexamined in the light of more recent data.

AN UPDATED FORECAST

Up to this point, the arguments and forecast presented in this paper have been summarized from a thesis done by Montrey under the direction of Utterback, and completed in 1982. [10] In this section of the paper, we will present data on what has actually happened since and use that knowledge to check and comment upon our earlier forecast.

While each component of the foregoing argument was generally accepted by knowledgeable observers in the forest products industry, the overall forecast was discounted by many of those same observers. Within the context of this industry the forecast substitution of a new product for a traditional one, oriented strand board, for plywood seemed wildly optimistic. By checking what has actually happened, we will see that deriving a summary forecast as we have done, using the Fisher-Pry technique, could have yielded substantial commercial advantages to anyone willing to believe in and act upon its seemingly optimistic result. What has actually happened in the ensuing five years?

In the foregoing argument, we gave economic as well as technical reasons for believing that COM-PLY would be a weak alternative. While saving slightly on material and extending the use of valued timber, COM-PLY required additional heavy capital outlays, making its costs roughly equal to those of plywood. At the same time, it offered little in the way of improved technical performance or potentials for improvement. COM-PLY seems to be a classic defensive response of proponents of an old technology attempting to beat back competition or to extend its life by adopting features of the new and combining old and new. In some instances, this appears to lend an element of "hybrid vigor" to an older technology. But that does not appear to have occurred in the case of COM-PLY. In fact none has been produced for several years.

We also suggested above that due to similarities in manufacturing process and the performance advantages of oriented strand board compared to waferboard, we might see a changeover by manufacturers of waferboard to production of the superior strand board product. This shift definitely has been occurring along with the adoption by waferboard manufacturers of certain of the improvement ideas embodied in strand board to the point that today in most analyses statistics for improved waferboard and oriented strandboard are combined. While there are variations, the trend is strongly toward the higher performance types of product represented by oriented strand board.

Figure 8 updates the trend of historical plywood sales which we originally presented in Figure 1. Figure 9 shows the recent most impressive surge in waferboard and OSB sales. In fact, sales of these new products has virtually quadrupled in the five years since we made our original forecast. Such explosive and sustained growth is virtually unprecedented for the group of products and industry analyzed here.

Finally, Figure 10 depicts the sales of waferboard and OSB as a percent of total structural panel sales. In other words, as the fraction of sales (f) of the new product as a part of total sales, the key variable of the Fisher-Pry equation. In fact, it appears that so far the forecast we generated with that equation is astonishingly accurate. The fraction of sales forecast by the equation for 1985 was 15% The actual number from our data is 14.8%! This apparently close match must be due more to luck than to forecasting method, but the important point is that the forecast we generated was several times the amount of sales expected by competent industry observers who were basing their estimates on less comprehensive and less quantitative techniques than those we have outlined above. The match is so close that there is no point in updating the calculated forecast, as we had originally intended. We are greatly encouraged by the match between the actual data shown in Figure 10 and the calculation's given in Figure 7.

Clearly a manager or strategist who had believed the forecast made five years ago could have gained commercial and competitive advantage from our analysis. In fact it appears that firms expanding their production of OSB are actually driving the industry. We believe that those plants are producing to capacity and selling their entire output while all of the variations in total demand upward and downward are being absorbed by the traditional product, plywood. We venture to hypothesize that the type of variance in production of a commodity, such as shown for plywood in recent years in Figure 8, is a clear sign of the vulnerability of that product to an emerging substitution such as the one depicted for waferboard OSB. The same pattern appears in charts of sales of several other commodities such as aluminum. We would urge others to test our hypothesis in detail using other cases. Early warning of impending decline is particularly important in industries producing highly standardized and commodity-like products, because responses to emerging threats are so often defensive in such industries and continue to be defensive beyond the point at which the traditional producers can constructively respond. In this case, the fact that established

Figure 8

HISTORICAL PLYWOOD SALES, 1938 - 1986

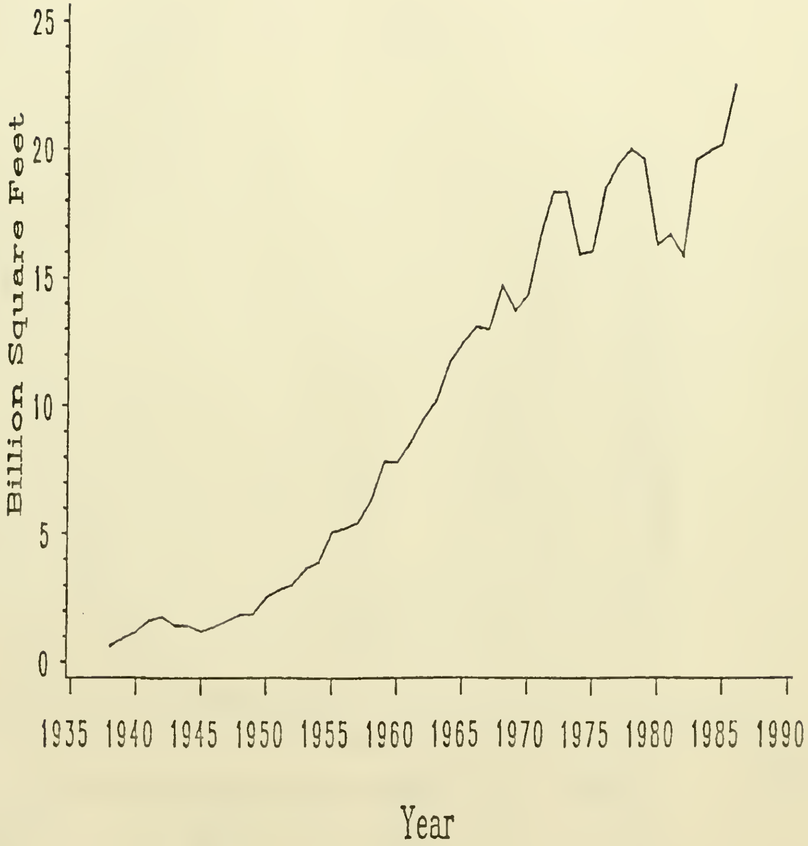


Figure 9

SALES OF WAFERBOARD/OSB, 1974 - 1986

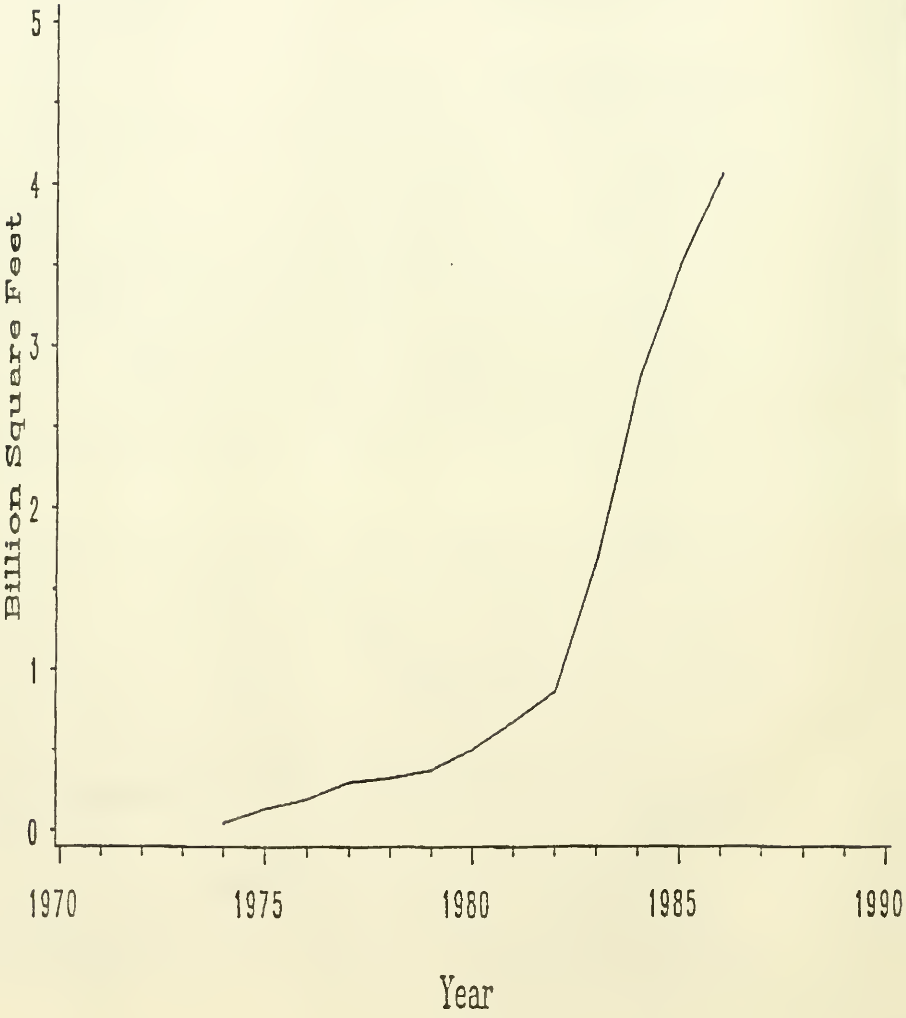
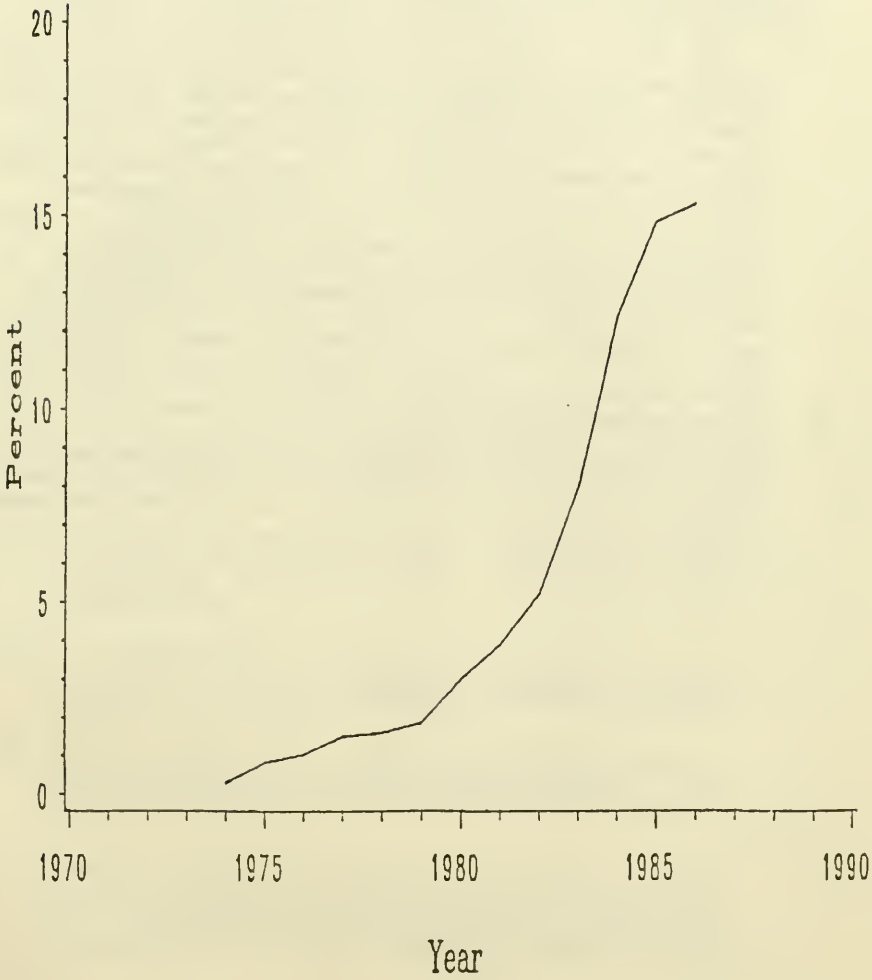


Figure 10

WAFERBOARD/OSB AS A PERCENT OF TOTAL STRUCTURAL PANELS



companies in the industry are actually among those producing the new product makes it rather an exception to the general rule though the complexion of competition is still changing rapidly. [11] Different firms may dominate the market for the new product than those which have dominated in the production of plywood.

The seeming validity of the estimates we produced for the Fisher-Pry equation five years ago leads us to go further out on a limb in terms of making a forecast now for the next five years. Even though Figure 8 appears to show a resurgent market for plywood, we confidently predict that severe drops in demand to below minimum levels experienced over the past decade will occur. We believe the surge in demand for plywood is a momentary phenomenon of the economic cycle in the housing market and that demand for plywood will fluctuate more and more wildly underpinned by the steady surge in growth seen in Figure 10 and forecast in Figure 7 for OSB. If anything, we would forecast more optimistically that the halfway penetration of the panel market by OSB might occur during the 1990s rather than shortly after the turn of the century, as predicted by our calculations. The ups and downs in the market created by economic cycles and surges in housing construction might actually speed the substitution by slowing defensive responses by plywood makers, while at the same time stimulating capacity expansions by those producing OSB. We hope that a check in five years will show this forecast to be as accurate as the one made five years ago appears to be.

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